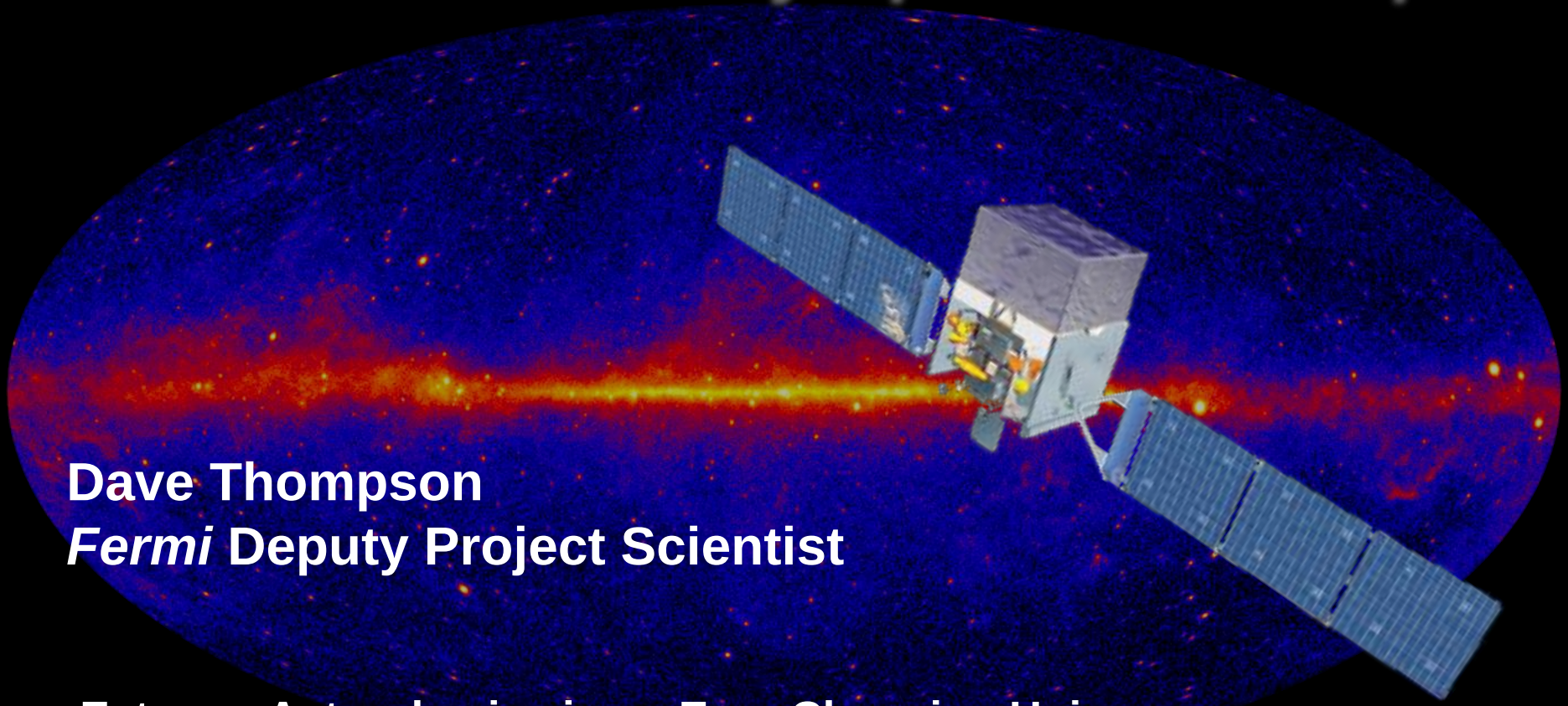
# New Opportunities for Time Domain Astronomy with the *Fermi Gamma-ray Space Telescope*



**Dave Thompson**
***Fermi* Deputy Project Scientist**

**Extreme Astrophysics in an Ever-Changing Universe - Time Domain Astronomy in the 21st Century**
**Ierapetra, Crete, June, 2014**

# Outline

Characteristics of the Fermi Gamma-ray Space Telescope

Three reasons why there are new Time Domain Astronomy (TDA) opportunities:

1. Scientific discoveries
2. Enhanced operations and data analysis
3. Improved and new multiwavelength/multimessenger facilities for synergy

# The *Fermi* Observatory

Large Area Telescope (LAT): 20 MeV to more than 300 GeV.
Observes 20% of the sky at any instant, entire sky every 3 hrs

International and interagency collaboration between NASA and DOE in the US and agencies in France, Germany, Italy, Japan and Sweden

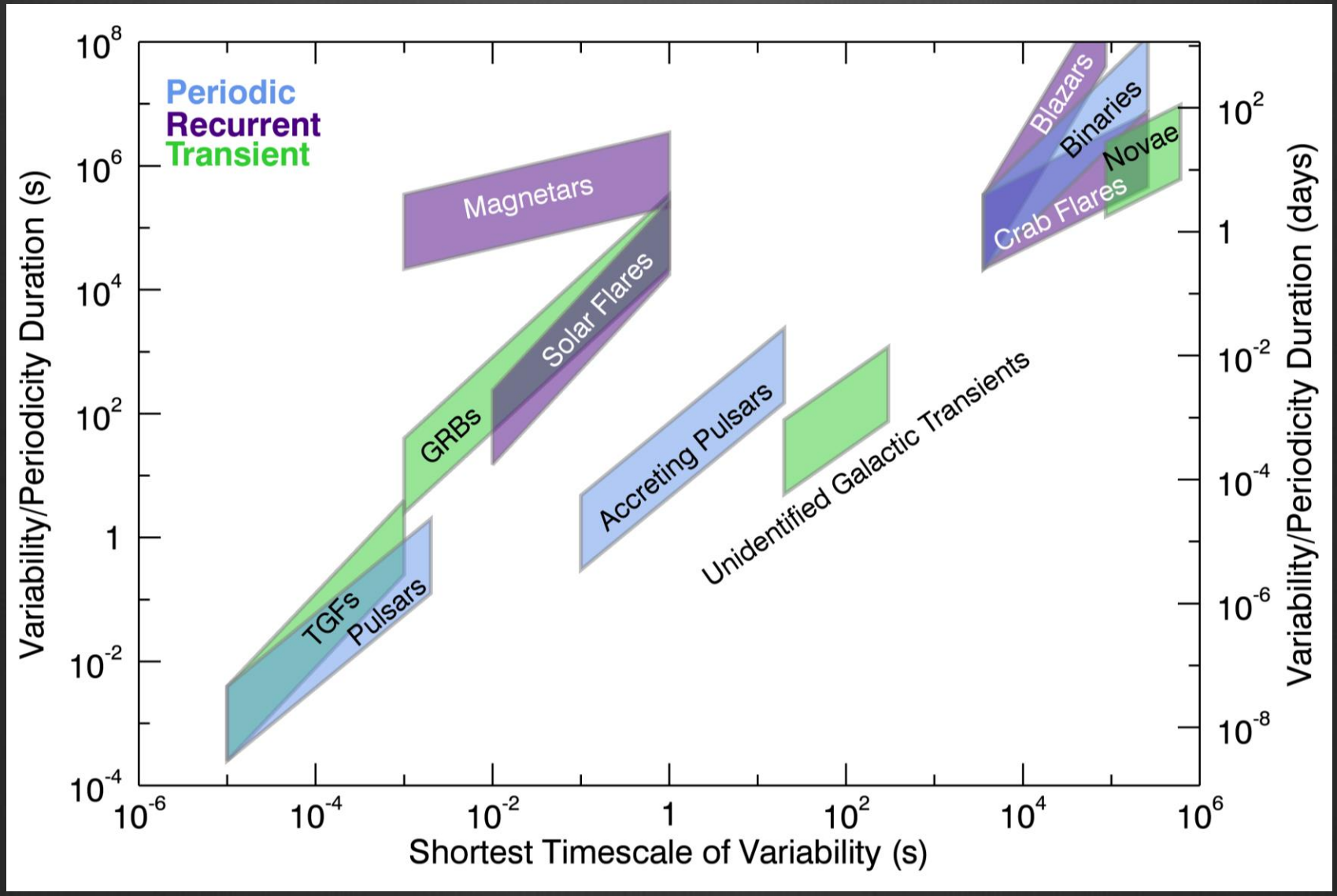
Gamma-ray Burst Monitor (GBM): 8 keV to 40 MeV.
Observes entire unocculted sky

- All the *Fermi* gamma-ray data become public immediately
- Analysis software, documentation, catalogs, and background models are available from the *Fermi* Science Support Center at Goddard, http://fermi.gsfc.nasa.gov/ssc/
- The *Fermi* instrument teams use GCN Notices, Astronomer's Telegrams, a weekly blog, and email lists to inform the community of sky activity.

# Time Domain Astronomy
# New Opportunities:

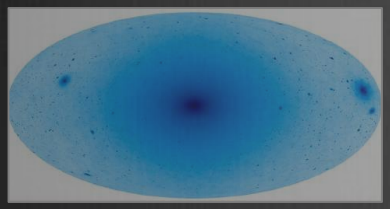
# Scientific Discoveries

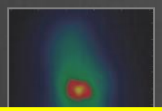
# Time Domain Astronomy
# *Fermi* Time Scales

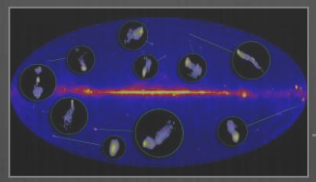


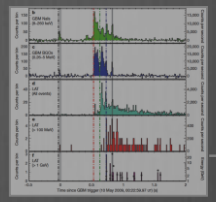
# *Fermi* Highlights and Discoveries

Dark Matter





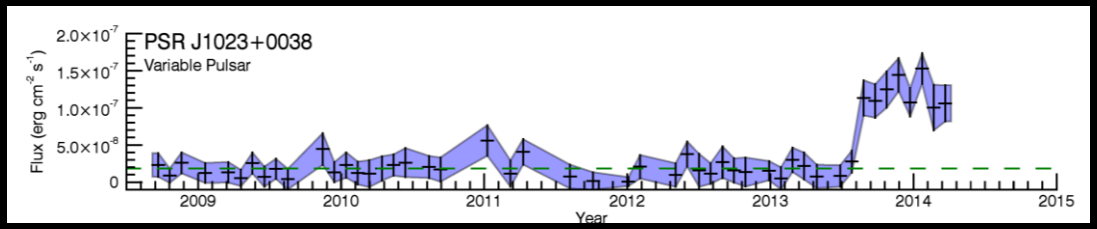




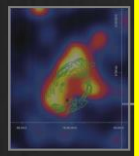
GRBs

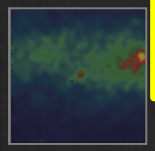
Blazars

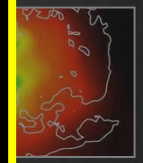
Gamma-ray emission from pulsars is now a firmly established topic in time domain astronomy.

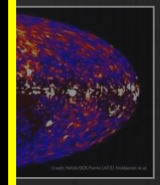



Stappers et al., ApJ Submitted, arXiv:1311.7506

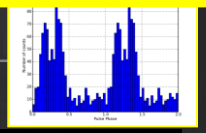




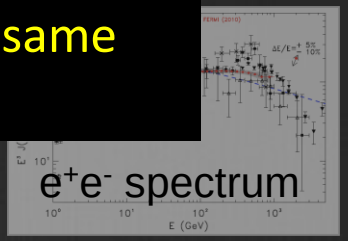




**Pulsars: isolated, binaries, & MSPs**



The radio emission from this binary ms pulsar ceased at the same time the gamma-ray flux increased by a factor of five.

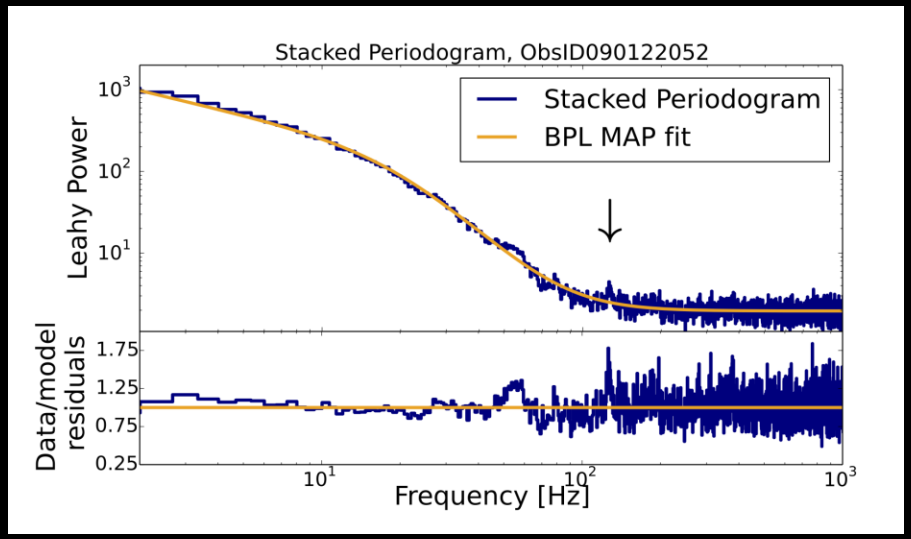



Unidentified Sources

# *Fermi* Highlights and Discoveries

Dark Matt

## Discovery of quasi-periodic oscillations in a "normal" Magnetar outburst



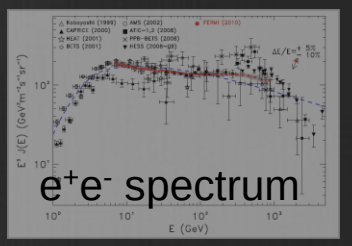

Huppenkothen et al., ApJ, 2013

**Pulsars: isolated, binaries, & MSPs**

Sun: flares & CR interactions

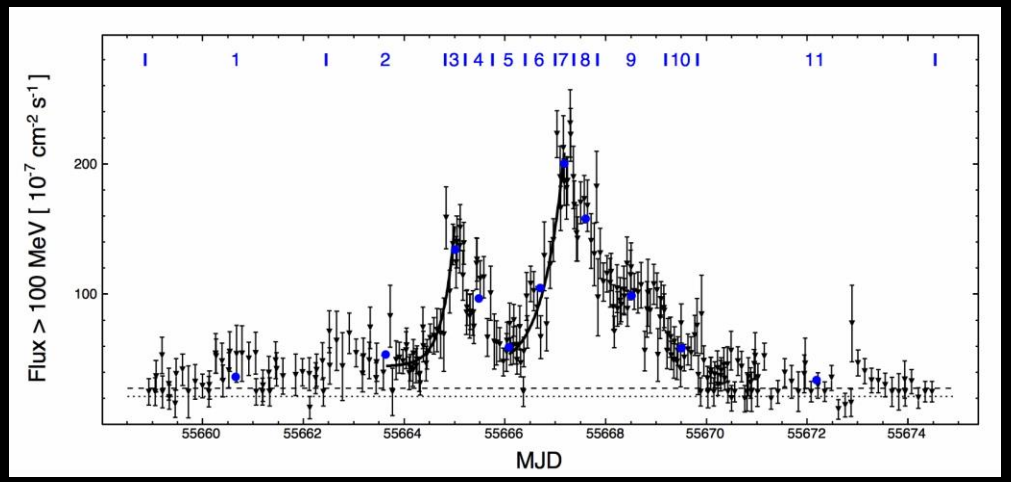
Terrestrial γ-ray Flashes

Unidentified Sources



# *Fermi* Highlights and Discoveries

Intense, rapid flares from the Crab Nebula




Buehler, R. et al.,ApJ, 2012

Dark Mat

Galactic

SNRs & PWN

Novae

γ-ray Binaries

**Pulsars: isolated, binaries, & MSPs**

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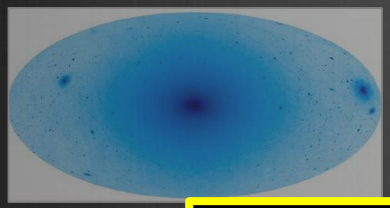
Terrestrial γ-ray Flashes

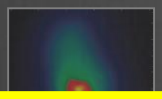
Unidentified Sources

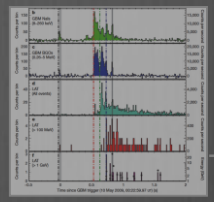
$e^+e^-$ spectrum

# *Fermi* Highlights and Discoveries

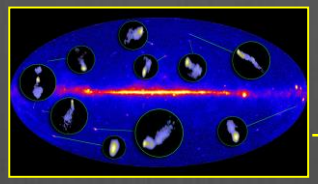
Dark Matter







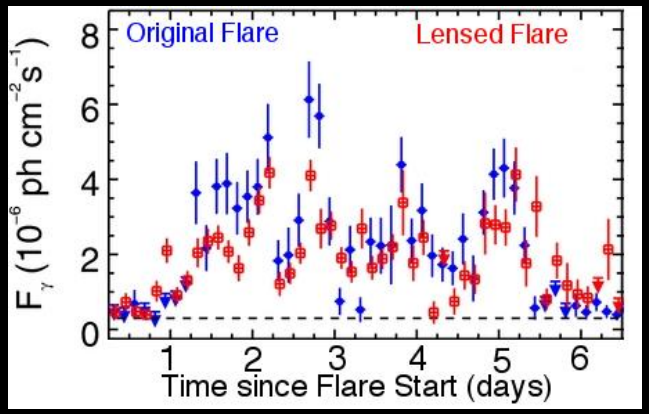
GRBs



**Blazars**

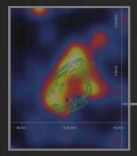
Pulsars

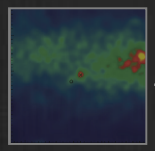
First gamma-ray measurement of a gravitational lens (blazar S3 0218+35)

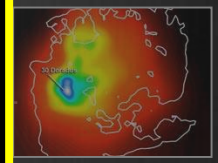


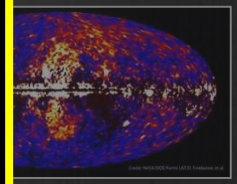

Delay of 11.46 days

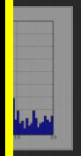
Cheung et al., ApJ, 2014

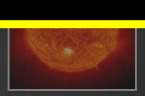


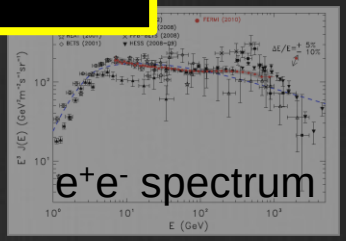













Terrestrial γ-ray Flashes

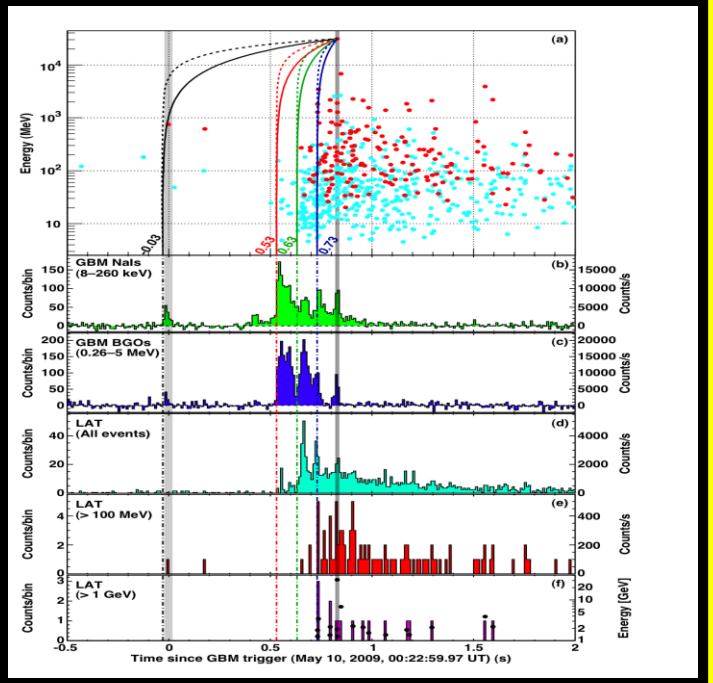
Unidentified Sources

# *Fermi* Highlights and Discoveries

Dark Matter

GRBs

Test of Quantum Gravity using a short Gamma-ray Burst




Abdo et al., Nature, 2009

Pulsars: isolated, binaries, & MSPs

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$e^+e^-$ spectrum

# Time Domain Astronomy New Opportunities:

# Operations and Analysis Enhancements

# A Key Issue:

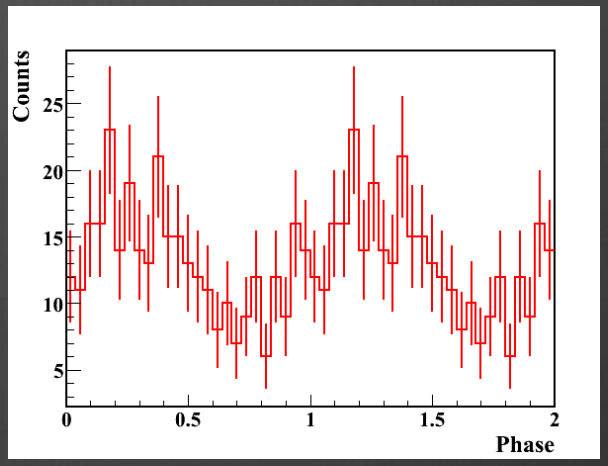
**In many cases, the limiting factor in gamma-ray astrophysics research is simple photon counting statistics. This is particularly true for any topic involving variability.**

**For this reason, anything that can be done to increase the number of detected gamma rays provides a direct boost to the science.**

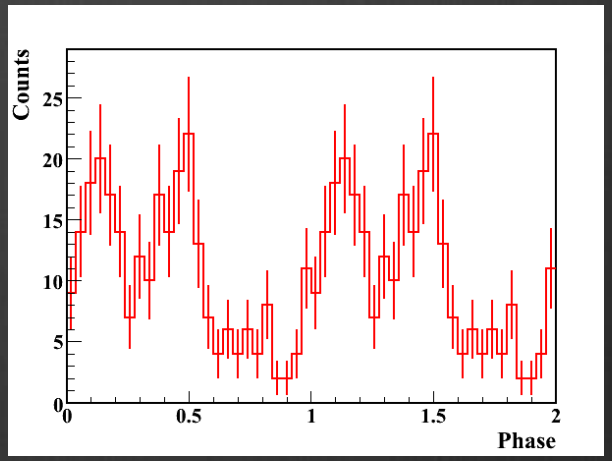
# Pulsars near the Galactic Center

- New observing strategy – higher photon rate helps overcome orbital motion and spindown noise
- Science
  - Determine the pulsar fraction of the Galactic center gamma-ray signal
  - More speculatively, discover a pulsar closely orbiting Sgr A* which would test fundamental properties of the black hole (c.f. Liu et al. 2012)

Example: PSR J1732-3131
gamma-bright, radio-quiet
pulsar 3.8° from Sgr A*




7 weeks of survey mode.
Search in (F0, F1).
P-value = 5.84e-2.




3 weeks of the new observing strategy.
P-value = 2.37e-8.

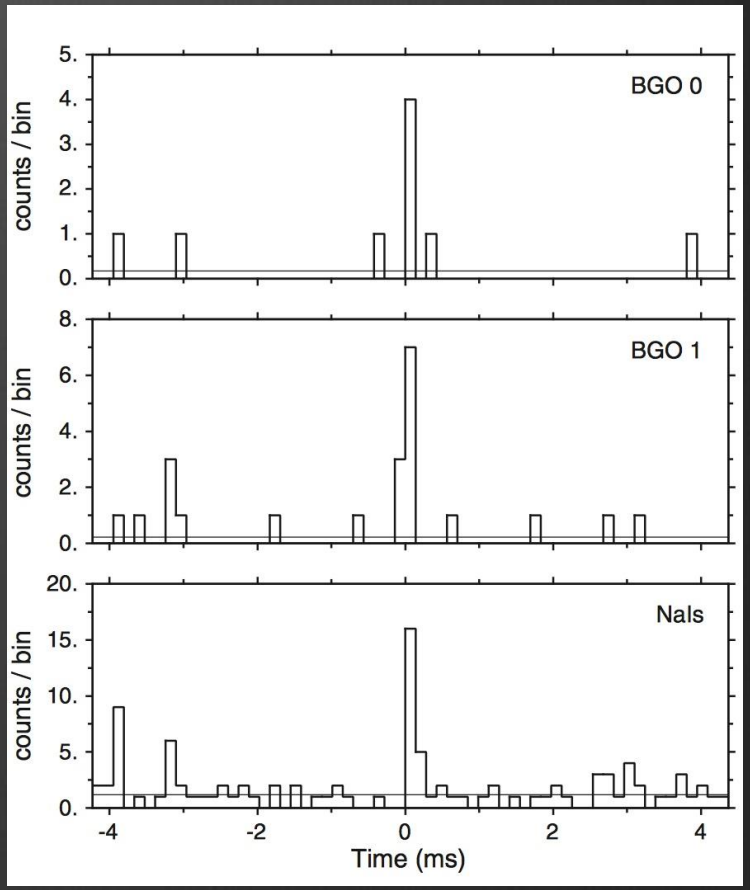
# Short Transients Detection with the Fermi GBM Time Tagged Events

- The GBM originally accumulated data in time bins, switching to individually time-tagged photons when a burst was detected.

- Switching to Continuous Time-Tagged Event (CTTE) Mode has enhanced the GBM sensitivity to short transients.

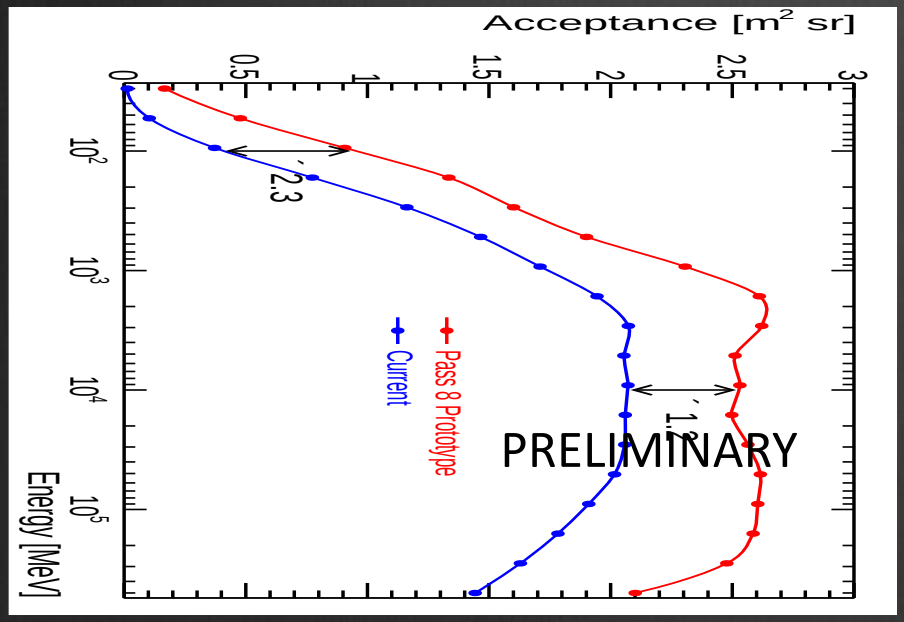
- The rate of Terrestrial Gamma-ray Flashes like the one shown here has increased by an order of magnitude (Briggs et al. JGR, 2013)

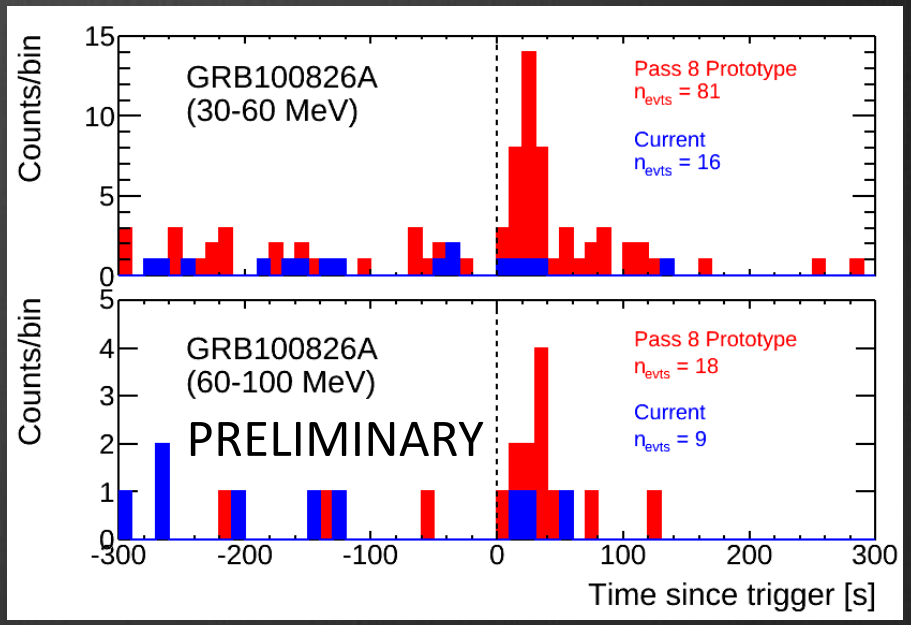
- The rate of short Gamma-ray Bursts is expected to double.



# LAT Analysis Upgrades: Pass 8

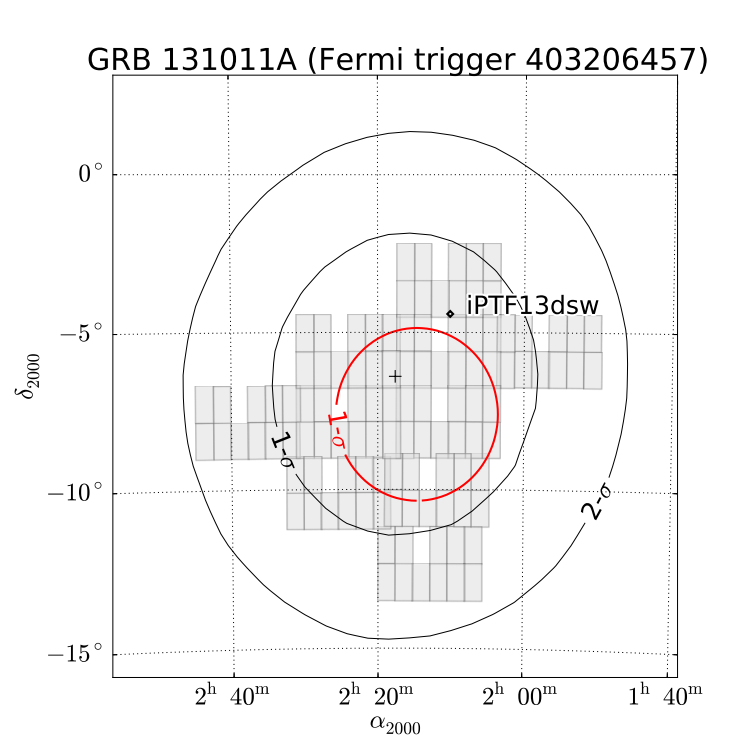
- **A major upgrade of the LAT (aka Pass 8) is nearing completion**
  - Complete revamp of LAT event reconstruction algorithms
  - More than double the acceptance (effective area x solid angle) below 100 MeV
  - Retroactively update entire *Fermi*-LAT data archive



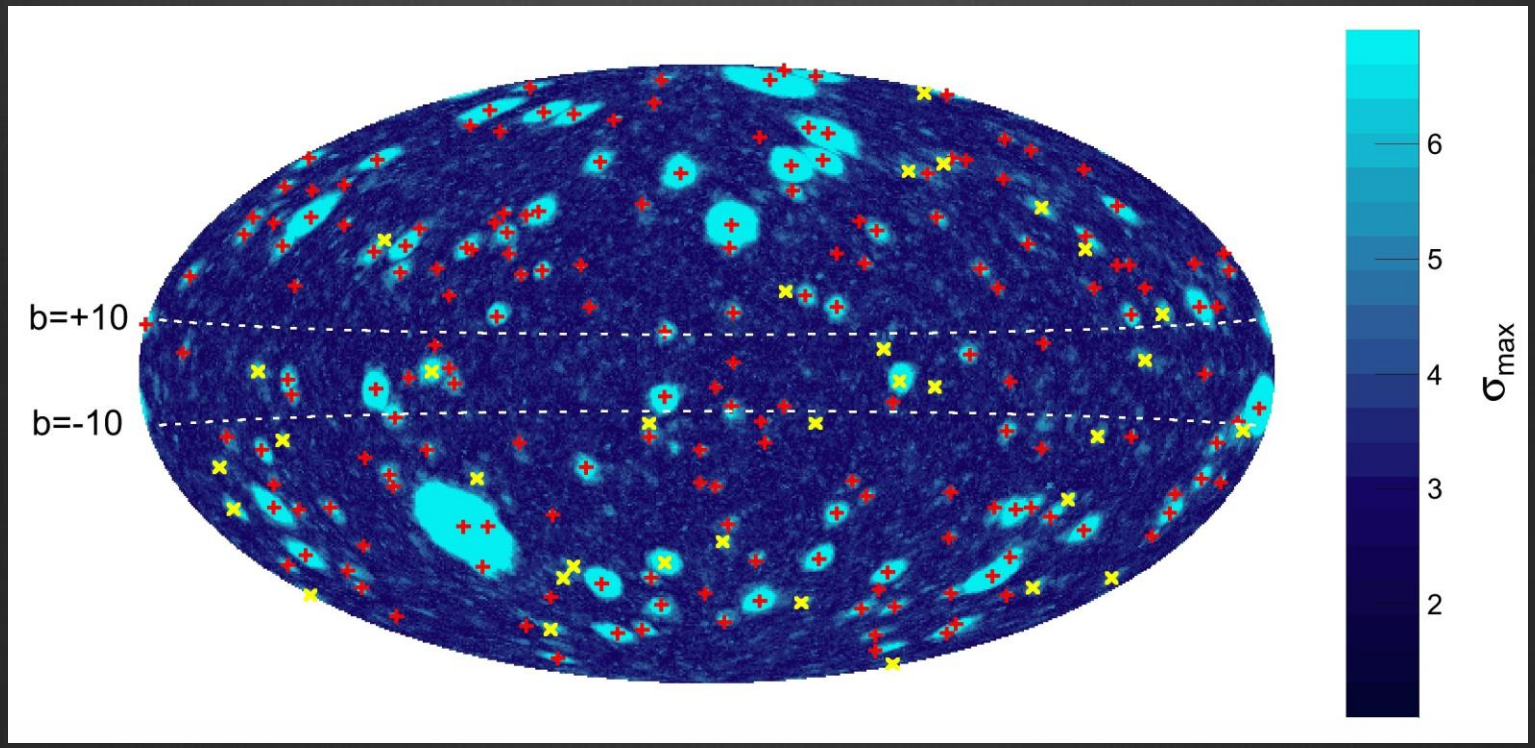
# Improved GBM Transient Localization

- The recent introduction of near-real-time GBM location uncertainty contours has increased the detection rate of optical afterglows
- In this example, the Palomar Transient Factory group found a candidate optical counterpart (Kasliwal et al GCN, 2013) within the 1σ statistical + systematic GBM error contour (smaller black oval).



# Improved LAT Transient Studies - FAVA

- The multi-year *Fermi* survey provides an accurate map of the "average" gamma-ray sky.
- The Fermi All-Sky Variability Analysis (FAVA) tool compares the sky in a given time interval with the average sky, identifying sources that show flux variability.

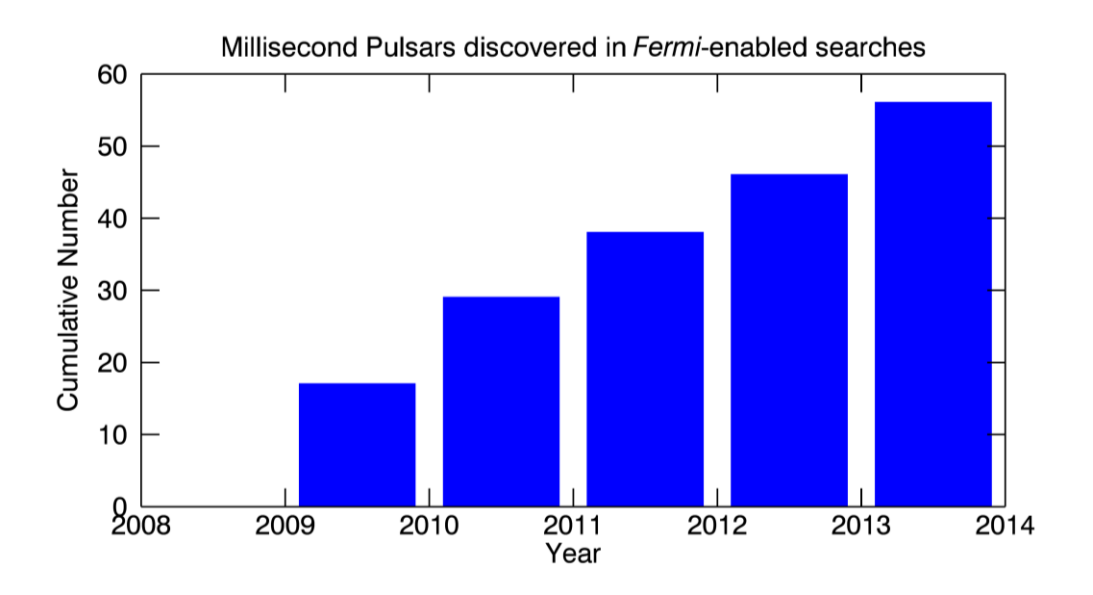


# Time Domain Astronomy
# New Opportunities:

# New and Improved Synergies

# Example: *Fermi* and ms pulsars

***Fermi*-LAT unidentified sources have turned out to be ideal places for radio astronomers to look for ms pulsars. The discovery rate has been nearly constant because radio flux is not correlated to gamma-ray flux.**




**The new synergy comes from the fact that some of these new ms pulsars are being incorporated into the pulsar timing arrays for gravitational wave studies that Dr. McLaughlin talked about on Monday.**

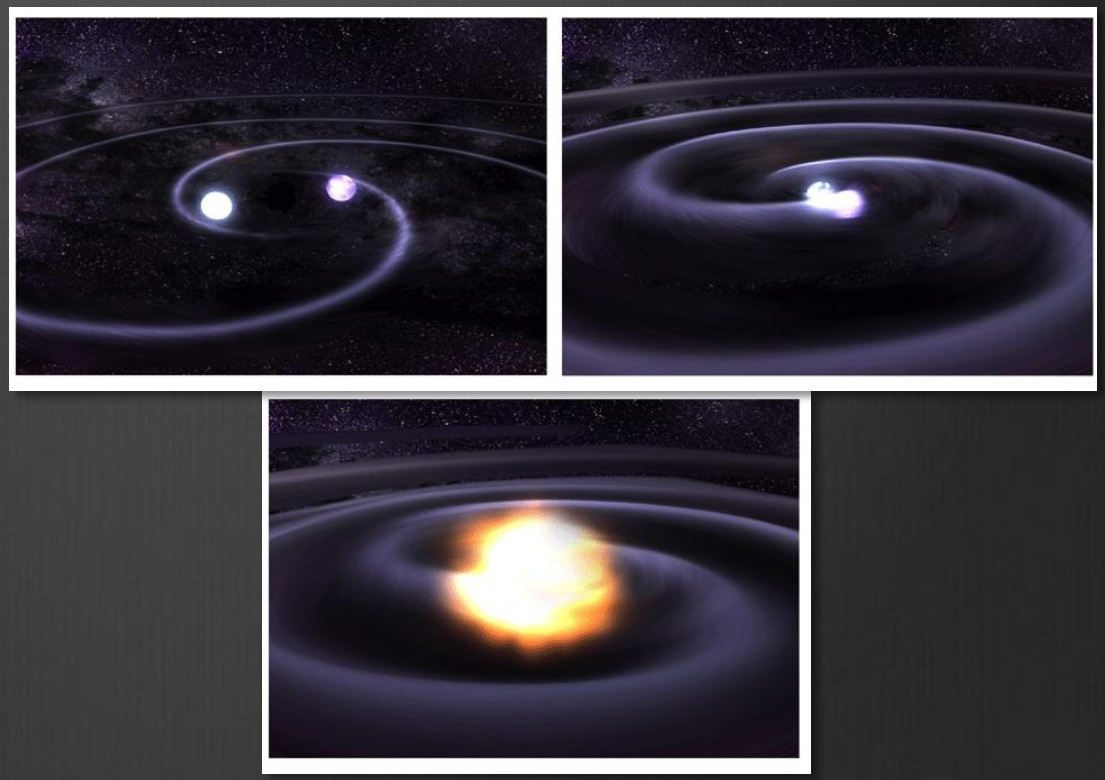
# Example: GRBs and Gravitational Waves

***Fermi*-GBM and Advanced LIGO/Virgo (>2015) should see coincident Gravitational wave/Electromagnetic emission or rule out NS-BH mergers as the progenitors of short GRBs**

Large rate of short bursts in GBM is key to coincident detections

GBM currently detects 40 short GRBs/year and will double this with the new pipeline

Afterglow detection/localization enhances science return



- Observations bring complementary information: Gravitational radiation → inspiral characteristics ; *Fermi* → jet properties & environment

# Summary

After six years in orbit, the *Fermi Gamma-ray Space Telescope* continues to scan the high-energy sky, providing a broad range of results related to Time Domain Astronomy.

The combination of scientific discoveries, significant improvements in operations and analysis for *Fermi*, and the growing array of multiwavelength/multimessenger facilities is opening new opportunities for Time Domain Astronomy. The future is bright!